L A N D S A T
Data Continuity Mission
LDCM

LANDSAT DATA CONTINUITY MISSION

LDCM Thermal Infrared Sensor Requirements Document

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Goddard Space Flight Center
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CM Foreword

This document is a Landsat Data Continuity Mission (LDCM) Project Configuration Management (CM)-controlled document. Changes to this document require prior approval of the applicable Configuration Control Board (CCB) Chairperson or designee. Proposed changes shall be submitted to the LDCM CM Office (CMO), along with supportive material justifying the proposed change. Changes to this document will be made by complete revision.

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1   <u>Introduction</u>

1.1   *Scope*

The Thermal Infrared Sensor Requirements Document (TIRS-RD) establishes the Level 3
procurement requirements for the thermal band sensor for the Landsat Data Continuity
Mission (LDCM). As a level 3 document, it contains the functional and performance
requirements.

1.2   *Mission Overview and Requirements Flow*

The TIRS instrument will fly on the LDCM spacecraft and operate independently of the
primary LDCM instrument, the Operational Land Imager (OLI). However, it will generally
be the case that the OLI and TIRS instrument will be collecting data simultaneously.

TIRS will be required to operate nominally on the observatory acquiring thermal scenes
(180km x 185km) on a 16 day repeat cycle, on the Worldwide Reference System - 2 with a
descending node of 10:00am at a nominal equatorial orbit altitude of 705km at the equator.
Mission Data will be collected over time intervals selected by the Flight Operations Segment.
The mission data is either stored, real-time telemetered or both concurrently.

When this document states a requirement for the TIRS to collect scenes, this is to be
interpreted to mean that the TIRS instrument is to collect imagery intervals sufficient to
produce the scenes. The WRS-2 Scenes are actually generated as part of the Data Processing
and Archive Segment after the data has been sent back to the United States Geological
Survey/ Earth Resources Observation and Science (EROS) facility in Sioux Falls, South
Dakota. The quality of the image data returned and processed at the EROS facility forms one
of the many steps for determining if requirements have been successfully meet. See the
LDCM Operations Concept Document, GSFC 427-02-02 for a more complete discussion of
the LDCM operations.

To ensure that the imagery data collected by the TIRS is of sufficient quality to produce
calibrated and registered Landsat data products, the TIRS developer is required to
demonstrate the production of calibrated and registered WRS-2 scenes on the ground using
TIRS data, unique TIRS data processing algorithms, and government-provided support data to
correct residual errors in the LDCM TIRS data so that the resulting corrected LDCM TIRS
data meet the imagery requirements of sections 5.6 and 5.7. The requirements of sections 5.6
and 5.7 presume that spacecraft bus performance is compliant with the Observatory Interface
Requirements Document, GSFC 427-02-03.

The general structure of the LDCM Project requirements is shown in Figure 1-1. The flow
down represented in this figure identifies which organization controls a set of requirements
and who has the authority to change those requirements.
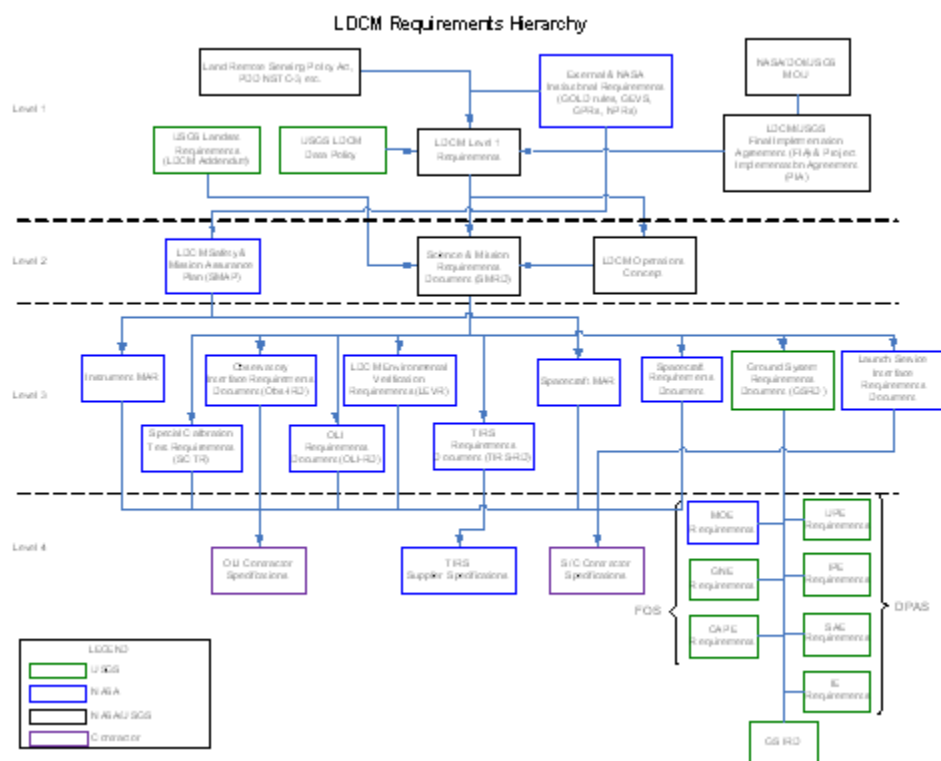
Figure 1 - 1   LDCM Requirements Flow

2   **<u>Reserved</u>**

3   <u>Functional Overview</u>

The LDCM TIRS developer is required to provide the Landsat thermal instrument for integration onto the LDCM spacecraft. The TIRS is to perform for a period of at least 3 years within the prescribed requirements. The TIRS is a two-band thermal imaging sensor providing imagery consistent with Landsat spectral, spatial, radiometric and geometric qualities as specified in Section 5 of this document. Terms used in this document may have unique meaning to the LDCM Project and are defined in the LDCM Acronym List and Lexicon, GSFC-427-02-06.

The TIRS is specified to provide two spectral bands with a maximum ground sampling distance, both in-track and cross track, of 120m for all bands. The TIRS will have a 185-km cross track swath width as measured at the equator at a nominal orbital altitude of 705-km. The LDCM Observatory will implement a yaw compensation maneuver to account for earth rotation effects on the image ground track.

The TIRS will produce image data and instrument ancillary data. The image and instrument ancillary data will be combined with observatory ancillary data to create Mission Data. Observatory ancillary data includes such items as spacecraft attitude, navigation, timing data and key telemetry values from sensors and spacecraft. Ancillary data provide all necessary image reconstruction information for later ground processing.

4   TIRS System Level

4.1   General

TIRS-24   The LDCM TIRS shall meet LDCM imaging requirements at all points throughout the orbit.

Rationale: Take an image anywhere within the orbit sunlit or eclipse.

TIRS-26   The LDCM TIRS shall acquire image and ancillary data equivalent to produce 400 non-contiguous WRS-2 Scenes, including the on-orbit calibration data, over any 24 hour period.

Rationale: The LDCM TIRS will be capable of acquiring sensor image data equivalent to 400 WRS-2 scenes per day plus any necessary calibration data. The 400 WRS-2 scenes account for all image collections in a 24-hour period. Vicarious calibration images are part of the 400 WRS-2 equivalent scenes. On-orbit calibration data will include lunar, solar, internal sources and is in addition to the 400 scenes. The WRS-2 scenes are actually generated on the ground and not on-orbit.

TIRS-28   The LDCM TIRS shall operate within the designed operational parameters when the LDCM Observatory points up to 15 degrees, off-nadir, to either side of the current orbit plane.

Rationale: The TIRS instrument must remain thermally stable, and fully function in off-nadir pointing attitudes. The image acquisition in this attitude is in lieu of an equivalent amount of nadir WRS-2 path image acquisition.

TIRS-30   The LDCM TIRS shall acquire up to 5 off-nadir image intervals per day as part of the 400 WRS-2 equivalent TIRS image and ancillary data.

Rationale: For rapidly changing conditions on the Earth, LDCM will be able to image either WRS-2 scenes or off-nadir scenes. These may or may not be a priority interval.

TIRS-32   The LDCM TIRS shall acquire image data equivalent to up to 77 contiguous, sun-lit scenes during any orbit.

Rationale: See the DRC-16 appendix to the LDCM Obs-IRD.

TIRS-34   The LDCM TIRS shall acquire image data equivalent to up to 38 contiguous, night scenes during any orbit.

Rationale: See the DRC-16 appendix to the LDCM Obs-IRD.

TIRS-36   The LDCM TIRS shall have no single command that could cause the loss of TIRS, assuming no previously failed TIRS components.

Rationale: There are no lock-out commands or TIRS internal one-way switches.

TIRS-38   The LDCM TIRS shall collect and transfer housekeeping data whenever power is applied to the instrument.

Rationale: Telemetry should be transmitted to the spacecraft whenever power is on the instrument.

4.2   TIRS System Lifetime

TIRS-41   The LDCM TIRS shall be designed to operate and meet all design specifications for 3 years after Observatory commissioning.

Rationale: Design life starts after acceptance, so instrument commissioning is in addition to the 3 years of operations. Performance margin must be applied to the design requirements to ensure 3 -year life still meets the stated performance requirements.

TIRS-43   The LDCM TIRS shall be designed for an overall Probability of Success of 0.8 or greater at the end of design life.

Rationale: End of design life Mission Success is defined as meeting 100% of the TIRS requirements at the end of the instrument design life.

4.3   Mission Phases

4.3.1   Ground Storage Phase

TIRS-49   The LDCM TIRS shall have a non-operational ground storage state that does not require intervention for at least 30-day periods

Rationale: This mode allows for storage of the instrument in the event of delays. This requirement does not preclude the use of N2 or some other purge gas during storage to ensure cleanliness and maintain nominal humidity. This requirement does not preclude safety monitoring of hazardous systems if required by the MAR.

4.3.2   Pre-Launch Phase

TIRS-52   The LDCM TIRS shall function in an ambient environment to facilitate functional testing.

Rationale: All hardware must operate (not necessarily to spec) to allow functional ground testing during I&T.

TIRS-54   The LDCM TIRS shall perform aliveness tests while mated to launch vehicle.

Rationale: To allow limited testing to provide confidence post encapsulation prior to launch.

4.3.3   Launch and Early Orbit Phase

TIRS-57   The LDCM TIRS shall remain in the Survival Mode during the initial Launch and Early Orbit Phase of the mission.

Rationale: TIRS operations should not interfere with the initial turn-on of the spacecraft; therefore there should be no need for checking the TIRS during the earliest phase of the mission.

TIRS-59   The LDCM TIRS shall have a launch readiness capability once every 24 hours
               after the initial launch attempt.

Rationale: To support a launch opportunity every day of the year there should not be any
instrument constraints to attempting a launch once every 24 hours.

TIRS-61   The LDCM TIRS, once fully integrated with the LDCM observatory, shall not
               have any instrument constraints to attempting a launch once every 24 hours,
               including every 24 hours after the initial launch attempt.

Rationale: Unforeseeable rocket, Observatory, and range conditions can delay launch. There is
no access to TIRS during this time. This requirement does not preclude the use of conditioned
air or purge gas.

4.3.4 Commissioning Phase

TIRS-64   The LDCM TIRS shall require no more than 60 days to complete
               commissioning activities once the observatory is ready to begin TIRS
               commissioning.

Rationale: This requirement is an allocation of the 90 days for observatory commissioning. It is
anticipated that the S/C will finish within 30 days, though it may not have achieved mission
orbit.

4.3.5 Operational Phase

   Reserved

4.3.6 Decommissioning Phase

   Reserved

4.4 Operational Orbit

TIRS-71   The LDCM TIRS shall meet all performance requirements when in the mission
               nominal orbit of 716 ± 12 km altitude and 98.2 ± 0.15° inclination.

Rationale: The WRS-2 grid will be used by the LDCM Observatory. TIRS' performance may
be evaluated at any point in the orbit based on this reference system.

4.5 Reserved

4.6 Autonomy

TIRS-75   The LDCM TIRS shall be capable of autonomously maintaining health & safety
               during the normal mission operations phase without ground intervention for 16
               days.

Rationale: In the event there is a failure in communicating with the spacecraft the TIRS can safe
itself while still powered up.

TIRS-78   The LDCM TIRS shall be capable of overriding autonomous functions, automatic safing or switchover via ground command.

Rationale: To diagnose failures and anomalies within the instrument

TIRS-80   The LDCM TIRS shall report autonomous state changes and reconfigurations in housekeeping telemetry.

TIRS-81   The LDCM TIRS shall, in the event of an anomaly, safely configure the instrument and report the anomaly to the ground in telemetry.

4.7 Availability

TIRS-83   The LDCM TIRS shall be available for collecting image data that meets the TIRS requirements at least 88% of the time during a WRS-2 Observation Period. The instrument is considered unavailable for times in which either: 1) the instrument is not meeting performance requirements, or 2) the instrument is performing calibration or maintenance procedures necessary for satisfying performance requirements. By definition, the instrument is considered available for all other times.

Rationale: Availability includes anomaly resolution of 12 hours per 28 days plus required calibration time of 5 minutes twice per orbit for calibration required for TIRS to meet the DRC-16 worst case scenarios.

4.8 TIRS Ground Support Equipment

4.8.1 TIRS Interface Simulator

TIRS-88   The LDCM TIRSIS shall simulate the TIRS response to hardware or discrete commands and commands received across the communications bus.

Rationale: The TIRS I/F simulator (TIRSIS) should respond in a manner like the flight TIRS for commands that do not come through command communication bus.

TIRS-90   The LDCM TIRSIS shall generate realistic response characteristics for analog telemetry, housekeeping telemetry and image and ancillary data.

Rationale: The TIRS I/F simulator (TIRSIS) must supply the spacecraft with realistic data to determine proper response to commands received.

TIRS-92   The LDCM TIRSIS shall provide an electrical load consistent with the interface control document between TIRS and the LDCM Spacecraft.

Rationale: To provide response characteristics to the spacecraft during power on testing.

TIRS-94   The LDCM TIRSIS shall generate internal timing response from LDCM Spacecraft timing signals, 1-pulse per second, and time of day messages

consistent with the interface control document between TIRS and the LDCM Spacecraft.

Rationale: To provide response characteristics to test spacecraft and instrument timing.

TIRS-96   The LDCM TIRSIS shall provide a MIL-STD-1553 remote terminal interface to validate messages exchanges between the TIRS and LDCM Spacecraft consistent with the interface control document between TIRS and the LDCM Spacecraft.

Rationale: To provide testing of the 1553 interface characteristics between spacecraft and instrument.

TIRS-98   The LDCM TIRSIS shall provide data flow over the High Speed Science Data Bus consistent with the interface control document between TIRS and the LDCM Spacecraft.

Rationale: To provide testing of the of the high-speed data interface characteristics between spacecraft and instrument.

TIRS-100   The LDCM TIRSIS shall provide responses to bi-level (both states) inputs consistent with the interface control document between TIRS and the LDCM Spacecraft.

Rationale: To provide testing of the of the bi-level command interface characteristics between spacecraft and instrument.

TIRS-102   The LDCM TIRSIS shall provide a flight-like TIRS instrument electrical interface connection for mating to the LDCM Spacecraft.

Rationale: The TIRSIS will mate to the S/C to test electrical interface. This may actually require multiple connectors to complete the electrical connection.

TIRS-104   The LDCM TIRSIS shall verify that TIRS flight software, embedded code, and database commands are correctly interpreted.

Rationale: To provide an interface test using flight code to verify correct flight instrument response to spacecraft commands.

4.8.2   TIRS System Test Equipment (TIRS-STE)

TIRS-107   The LDCM TIRS System Test Equipment shall provide an interface to the Spacecraft System Test Equipment for real-time data capture and recording of data as received from and transmitted to the LDCM spacecraft.

Rationale: For post-integration test evaluation at the spacecraft contractor's facility

TIRS-109   The LDCM TIRS-STE shall test all electrical interfaces between the TIRS and the spacecraft including but not limited to power, clock, command, and telemetry.

TIRS-110   Upon command, the LDCM TIRS-STE shall record, display, distribute, and
                analyze the data received from the TIRS and ground support equipment
                including instrument test points.

Rationale: The ability to gather and analyze TIRS data local to the instrument (i.e., not relying
on remote transmission of data for analysis) is important during observatory I&T to facilitate
efficient testing activities.

TIRS-111   Upon command, the LDCM TIRS-STE shall capture and time tag all data as
                received from the TIRS and STE inclusive of image and ancillary data.

Rationale: Data capture permits post-test analysis and provides a historical record of all data that
is generated during I&T activities.

TIRS-113   Upon command, the LDCM TIRS-STE shall display real-time TIRS
                housekeeping and diagnostic data.

TIRS-114   Upon command, the LDCM TIRS-STE shall generate hard copy print out of all
                analysis results, screen dumps, and processed data.

TIRS-115   The LDCM TIRS-STE shall generate data on, and receive data from, hard media
                (i.e., CD and/or DVD).

Rationale: Hard media addresses the need to use any industry typical, permanent media that
allows for the mission lifetime storage of test and engineering data.

TIRS-117   The LDCM TIRS-STE shall furnish all power, timing signals, and commands
                needed by the TIRS and normally supplied by the spacecraft.

TIRS-118   The LDCM TIRS-STE shall physically isolate all power lines from signal lines.

Rationale: To protect communication circuits from high voltage TIRS should use shielded and
separate cables.

TIRS-120   The LDCM TIRS-STE power supplies shall have short-circuit protection and
                voltage-transient protection.

TIRS-121   The LDCM TIRS-STE shall be able to perform a self-test.

TIRS-122   The LDCM TIRS-STE shall be able to send commands to the TIRS elements

TIRS-123   The LDCM TIRS-STE shall be the able to control the simulated S/C interfaces
                and external calibration GSE

TIRS-124   The LDCM TIRS-STE shall receive data from the TIRS, STE, and supporting
                test equipment.

TIRS-125   The LDCM TIRS-STE shall perform health and safety checks to guarantee the
                safety of the TIRS elements and test equipment (in all states).

TIRS-126   Upon command, the LDCM TIRS-STE shall analyze the data in real-time as
                well as in an off-line mode.

TIRS-127   The LDCM TIRS-STE shall analyze and process image data, ancillary data, and instrument housekeeping data within 2 hours of collection, exclusive of the time required to collect the data.

TIRS-128   The LDCM TIRS-STE shall include engineering, instrument data trending, and sensor data analysis tools.

Rationale: This will help determine instrument performance.

TIRS-130   The LDCM TIRS-STE shall simultaneously operate and monitor the instrument, and perform data analysis.

TIRS-131   The LDCM TIRS-STE shall display instrument engineering data as well as external GSE data.

TIRS-132   The LDCM TIRS-STE shall display information corresponding to a set of pre-stored display templates.

TIRS-133   The LDCM TIRS-STE shall display raw data in operator-selectable formats, including digital numbers (i.e. hexadecimal, integer, unsigned integer, etc.) and real values in SI units.

TIRS-134   The LDCM TIRS-STE shall have an operator interface.

TIRS-135   The LDCM TIRS-STE shall provide an interface with the TIRS Calibration Test Equipment so that data will be entered into a data system and test correlated.

TIRS-136   Upon command, the LDCM TIRS-STE shall monitor all command states, selected voltages, currents, temperatures, and other telemetered and derived parameters in real-time.

TIRS-137   The LDCM TIRS-STE shall monitor any TIRS deployments in real-time.

TIRS-138   The LDCM TIRS-STE shall monitor any TIRS pyrotechnic events in real-time.

TIRS-139   The LDCM TIRS-STE shall automatically protect the instrument if appropriate operator action is not taken.

TIRS-140   The LDCM TIRS-STE shall verify all operational modes of the TIRS.

TIRS-141   The LDCM TIRS-STE shall record and alert the operator of any out-of-tolerance items as they occur.

TIRS-142   Upon command, the LDCM TIRS-STE shall bypass or terminate all automatic sequences resident in the instrument or in the LDCM TIRS-STE.

TIRS-143   The LDCM TIRS-STE shall operate, at the first application of power during instrument integration and continuing through all periods of operation and/or test, a limits check program.

TIRS-144   The LDCM TIRS-STE shall maintain a command and operational time log.

TIRS-145   The LDCM TIRS-STE shall support on Ethernet I/O port for data sharing with the spacecraft ground support equipment.

4.8.3 Mechanical Ground Support Equipment (M-GSE)

TIRS-147   The LDCM TIRS M-GSE shall provide mechanical support for the integration of the TIRS onto the spacecraft.

TIRS-148   The LDCM TIRS M-GSE shall provide support for the performance verification, environmental testing and calibration of TIRS at the Observatory level.

4.8.4 Shipping/ Storage Containers

TIRS-150   The LDCM TIRS Instrument Shipping & Storage Container shall incorporate means of measuring and recording shocks, temperature and humidity within the container.

TIRS-151   The LDCM TIRS Instrument Shipping & Storage Container shall have external indicators for temperature, humidity, and pressure monitoring.

TIRS-152   The LDCM TIRS Instrument Shipping & Storage Containers shall be suitable for use in the clean room, after a minimal amount of cleaning.

Rationale: The TIRS instrument may be operated in the Shipping & Storage container in close proximity to the spacecraft.

4.9 TIRS Simulator

TIRS-155   The LDCM TIRS Simulator shall operate both mated to and independent from the LDCM Spacecraft Simulator.

Rationale: In support of diagnostics of the Flight TIRS is may be necessary to run the TIRS simulator "off-line" from the spacecraft. This functionality may also be useful for developing response characteristics in the simulator.

TIRS-157   The LDCM TIRS Simulator shall realistically simulate the TIRS response characteristics appropriate to LDCM Spacecraft attitude changes, such that telemetry responses represent what would be received from the LDCM TIRS in flight.

TIRS-158   The LDCM TIRS Simulator shall simulate the operations of the TIRS command and data-handling system.

TIRS-159   The LDCM TIRS Simulator shall simulate the operations of the TIRS power distribution system.

TIRS-160   The LDCM TIRS Simulator shall simulate the operations of the TIRS telemetry and command response system.

Rationale: During FOT training for software updates, as applicable, the simulator should simulate the appropriate telemetry responses to commands.

TIRS-162   The LDCM TIRS Simulator shall simulate the nominal and diagnostic operations of the focal plane electronics.

Rationale: This should include generating/producing nominal image test patterns and diagnostic image data as is appropriate.

TIRS-164   The LDCM TIRS Simulator shall interface with the LDCM Spacecraft Simulator using all flight-like connections specified in the ICD.

Rationale: So that the TIRS software simulator can talk to the S/C simulator without have to define a unique electrical and connector interface.

TIRS-166   The LDCM TIRS Simulator shall simulate all TIRS operational modes and mode transitions.

TIRS-167   The LDCM TIRS Simulator shall verify valid TIRS commands, table updates and flight software modifications.

TIRS-168   The LDCM TIRS Simulator shall receive commands in any flight valid format and data rate.

Rationale: Not anticipating variations if a 1553 interface is used, so this could be an easy requirement. However, if the meaning of discretes can change or if there are other ways to command the TIRS then they should be modeled.

TIRS-170   The LDCM TIRS Simulator shall receive, process, and execute flight software updates that may include complete version updates, patches, and table updates, that are identical to updates for the flight TIRS.

TIRS-171   The LDCM TIRS Simulator shall accurately simulate the timing of command responses.

TIRS-172   The LDCM TIRS Simulator shall generate real-time housekeeping telemetry streams with representative TIRS data in all valid formats and data rates.

TIRS-173   The LDCM TIRS Simulator shall generate TIRS image and ancillary data streams with representative data in all valid formats and data rates.

Rationale: This should include the effects of compression if present and without compression if turned off.

TIRS-175   The LDCM TIRS Simulator shall simulate the response characteristics of failed TIRS subsystems and components.

TIRS-176   The LDCM TIRS Simulator shall simulate user-defined faults in the TIRS.

TIRS-177   The LDCM TIRS Simulator shall respond to real-time operator changes in the configuration of the simulated TIRS.

TIRS-178   The LDCM TIRS Simulator shall accept inputs from the user to set and change simulation variables.

Rationale: allows users to inject faults, vary initial conditions, etc.

TIRS-180   The LDCM TIRS Simulator shall accept inputs from the user to set and synchronize simulation time with observatory clock time and ground system time.

Rationale: To synchronize the events on-orbit with the events in the simulation

TIRS-182   The LDCM TIRS Simulator shall save both executed simulations and simulation data.

Rationale: This allows trainers to establish a baseline set of training simulations and to be able reproduce a simulation.

TIRS-184   Upon command, the LDCM TIRS Simulator shall run previously executed simulations.

Rationale: This allows trainers to establish a baseline set of training simulations and to be able reproduce a simulation.

TIRS-186   The LDCM TIRS Simulator shall operate using the TIRS flight software, embedded code, databases, constraints, limits, parameters, and metrics.

Rationale: Ensures simulator behaves like flight article.

4.10 TIRS Mechanical Simulator

The Spacecraft vendor requires a high fidelity mechanical and thermal simulator of the TIRS instrument in order to perform spacecraft thermal vacuum testing prior to TIRS delivery. The simulator must be capable of flying in place of TIRS in the event TIRS is not delivered prior to LDCM launch.

TIRS-848   The TIRS High Fidelity Mass Simulator (HFMS) shall consist of a Sensor Unit (SU), Main Electronics Box (MEB) and Cryocooler Electronics box (CCE).

TIRS-849   The HFMS SU shall emulate the geometric, mass and thermal characteristics of the TIRS SU.

Rationale: HFMS does not need to meet optical characteristics because there is no impact on OLI.

TIRS-851   The HFMS MEB and CCE boxes shall emulate the geometric dimensions of the MEB and CCE electronics boxes only.

Rationale: The mass of spacecraft mounted TIRS components is not significant enough to impact ACS spacecraft design.

TIRS-853   The HFMS shall meet all applicable flight requirements for structural integrity, contamination control, and cleanliness as specified in the LEVR.

Rationale: HFMS may be required to fly in place of TIRS.

TIRS-855   The HFMS shall represent the stowed configuration only.

Rationale: The spacecraft ACS system is robust enough to handle the stowed configuration configuration on orbit, even though it will be designed for the configuration in which the actual TIRS earth shield deploys. The cost of qualifying a deployable shield for a simulator will be high and that added fidelity is not required.

TIRS-858   The HFMS SU shall match the TIRS geometric shape and maintain the flight
                mounting interface.

Rationale: The HFMS needs to meet the TIRS-to-SC ICD mounting requirements.

TIRS-860   The mass properties (mass, center of gravity, and stowed inertia) of the HFMS
                SU shall be controlled and measured to the same tolerances as the flight SU.
                HFMS SU Mass: +/- 1% (TBR) of SU NTE mass per ICD, measured to
                accuracy of 0.2% (TBR). CG Location: +/- 2 cm (TBR) of predicted SU CG
                location in MICD, measured to accuracy of +/- 1 cm (TBR). Inertia need only
                be calculated and reported.

TIRS-862   The HFMS shall use flight-like interface fittings so that the HFMS mounts
                correctly to the instrument deck and replicates the correct reaction forces
                between the simulator and deck.

TIRS-864   The HFMS SU, MEB and CCE shall include flight-compatible connectors for
                all spacecraft harness mating interfaces located to 0.5 inch and with correct
                connector orientation.

TIRS-865   Interface terminators for the spacecraft harness shall be provided by TIRS to
                terminate the SC side of the harnessing as deemed necessary by the spacecraft
                vendor.   (SC harness remains the same; TIRS side would need heater and
                thermistor circuitry- terminating the others).

TIRS-867   The HFMS components shall incorporate the same lift points and handling
                capability as the flight units.

TIRS-868   The HFMS shall include a radiator mock-up with correct physical geometry
                including flight-like MLI on back-side.

Rationale: Analysis indicates that OLI is not affected by presence of TIRS radiator

TIRS-870   The TIRS HFMS SU mounted to the deck shall have MLI blankets installed in a
                flight-like configuration representative of the physical shape, but not optically
                the same as flight.

Rationale: Analysis indicates that OLI is not affected by TIRS optical properties.

TIRS-872   The HFMS CCE and MEB components shall be an accurate representation of
                the geometric shape, with flight-like thermal interfaces and coatings, and
                terminations for the spacecraft flight harness. MLI blankets and thermal control
                devices will be provided by Orbital.

TIRS-873   All elements of the HFMS shall be vacuum compatible with the ability to be
                cleaned to meet LDCM contamination control standards.

TIRS-875   The HFMS SU shall include test heater circuits and temperature sensors that
                will allow the spacecraft vendor to control the TIRS-to-deck interface via
                external heater racks during thermal vacuum testing to match the STOP analysis
                results.

TIRS-876   The HFMS SU shall include survival heater circuits powered through the flight electrical interface connections at the SUPD to simulate TIRS in Survival mode and one operational mode to be determined by the SC vendor.

TIRS-877   The HFMS SU shall include flight-like MLI blanketing interfaces with the SC deck including the TIRS provided MLI skirt

TIRS-878   The HFMS SU shall include properly grounded MLI with a Kapton outer layer and vented in a flight-like configuration.

5   Imagery Requirements

5.1   General

This section establishes the requirements for characteristics and quality of images to be provided by the TIRS. This section also describes the requirements for image correction that are necessary in order to verify TIRS performance. The LDCM TIRS image requirements will only apply to nadir imaging. Off-nadir imaging is important to meeting LDCM mission requirements but they will not drive the instrument performance. The requirements on TIRS concerning off-nadir are to ensure that the instrument design operates reliably and off-nadir does not influence the operational life of the instrument.

TIRS-192   The LDCM TIRS shall have a minimum field of view that provides a 185-km cross-track swath width at the equator for the LDCM operational orbit.

Rationale: Earth flattening and control accuracy causes the altitude of a circular orbit to vary from 704 km at the equator to just over 728 km at the maximum latitude. Since, for a given instrument field of view, the swath width will be smallest where the orbit is closest to Earth. If the swath width requirement is met at the equator, it will be satisfied elsewhere.

5.2   TIRS Operational Modes and Conditions

TIRS-195   The LDCM TIRS shall transition into any mode and state on command.

Rationale: Ground commands can override any autonomous actions of the TIRS. Through ground commands, TIRS can be placed in any mode and state including power off.

TIRS-197   The LDCM TIRS shall not respond to commands that place the instrument into a ground test only mode after launch.

Rationale: Should not be possible to command the instrument into non-operational (ground test, storage, etc.) modes that prevent the instrument from returning to nominal operations.

TIRS-199   The LDCM TIRS shall provide a telemetry message identifying each time the instrument changes state or mode.

Rationale: The spacecraft needs to know/report if the instrument has placed itself into the various modes.

5.2.1   Survival

TIRS-202   The LDCM TIRS shall be capable of entering an unpowered instrument survival state from any powered modes without receiving a warning or preparatory command from the spacecraft.

Rationale: Survival is a power off condition and as such, the instrument may be placed into this state without any warning. The LDCM TIRS will receive only survival heater power in the instrument survival state; the spacecraft will supply survival heater power but that power does not go through any TIRS electronics.

TIRS-204   The LDCM TIRS shall have survival heaters to ensure the instrument stays
             within the design, survival temperature range.

Rationale: In this state, the spacecraft will supply survival heater power but the sizing, and
placement of the heaters is the TIRS developer's responsibility.

TIRS-206   The LDCM TIRS shall meet all performance specifications within 1.5 days after
             power up after being in the survival state for less than or equal to 1.0 day.

Rationale: Goal is to achieve a survival recovery period that is consistent with OLI.

TIRS-208   The LDCM TIRS shall meet all performance specifications within 9 days after
             power up after being in the survival state for greater than 1.0 day.

Rationale: Goal is to achieve a survival recovery period that is consistent with OLI.

5.2.2 **Power-On**

TIRS-211   The LDCM TIRS electronics shall be powered on at any temperature between
             the cold survival limit and the upper qualification limit.

Rationale: It is possible for power to be applied to the TIRS anywhere between the cold survival
limit and the upper qualification limit. Application of power at the cold survival limit enables
the instrument to achieve its operational temperature range. Nominally, the instrument will not
be turned-on at temperatures exceeding the upper operational limit. Note: This requirement is
consistent with requirement LEVR-1099 which provides further details on hot and cold
temperature turn-on limits.

TIRS-213   The LDCM TIRS shall transition from a non-operational mode to an operational
             mode only via ground command.

Rationale: The instrument can transition to safer modes automatically but not up to more
complex modes.

5.2.3 **Diagnostic Capabilities**

TIRS-216   The LDCM TIRS shall implement a capability to return dedicated diagnostic
             data to assist in instrument characterization or anomaly investigation.

Rationale: The diagnostics capability may require different data rates to return dedicated
diagnostic data to assist in instrument characterization or anomaly investigation.

TIRS-218   The LDCM TIRS diagnostic capability shall enable TIRS to output detector
             response data from every physical detector on the TIRS focal plane.

TIRS-219   The LDCM TIRS shall provide the capability to disable any on-orbit processing
             operation that combines or compresses raw detector data in any manner.

Rationale: To support early orbit checkout and for anomaly resolution, examples of such
processing operations include TDI and compression.

TIRS-221   The LDCM TIRS shall provide the capability to disable any on-orbit processing
                operation that normalizes or applies any uniformity correction to detector data in
                any manner.

Rationale: To support early orbit checkout and for anomaly resolution, example of such
processing operations is non-uniformity correction.

5.2.4   Safe Condition

TIRS-224   The LDCM TIRS shall implement instrument safing capabilities in which TIRS
                is in a condition that protects all its functions from degradation and damage.

Rationale: TIRS needs to be able to place itself in a safe condition as necessary, including a
nominal standby mode of operations where all instrument constraints (thermal, pointing, etc.) are
maintained, but no imaging is performed.

TIRS-226   The LDCM TIRS shall complete transition to a safe state within 45 seconds
                after receiving the command to enter this state while in any powered mode or
                condition.

TIRS-227   The LDCM TIRS shall provide a safe state that maintains the design operational
                environments.

Rationale: This mode maintains operational temperatures and other environment ready for
nominal operations.

TIRS-229   The LDCM TIRS shall autonomously enter into a safe state when a TIRS
                detected failure could result in damage to the TIRS.

TIRS-230   The LDCM TIRS shall continue to collect and transmit housekeeping data to the
                spacecraft when in its safe state(s).

Rationale: Mission or calibration data would not be automatically transferred to the spacecraft,
but it could be if commanded to send the data.

TIRS-232   The LDCM TIRS shall remain in a safe state without damage while the LDCM
                Observatory performs orbit correction maneuvers.

Rationale: The instrument is not required to meet performance requirements during orbit
correction but is not to be damaged by spacecraft maneuvers.

TIRS-234   The LDCM TIRS shall autonomously enter its safe state after failing to receive
                the stored number of consecutive time code data packets from the spacecraft.

Rationale: The TIRS will be continuously receiving a time code message unless the S/C C&DH
system is down. If the C&DH is down then TIRS should be safed.

TIRS-236   The LDCM TIRS stored number of missed time code packets which result in
                safing of TIRS shall be alterable on-orbit over the range of 1 up to a maximum
                of 63 consecutive time code data packets.

Rationale: The value selected to enter the safe state will depend on instrument and S/C design.

TIRS-238   The LDCM TIRS shall protect itself from or be immune to damage caused by direct solar illumination on or into any TIRS surface or aperture while in its safe state.

Rationale: In the event of a spacecraft anomaly, there is a chance that the sun may illuminate TIRS from any angle for an undefined period of time.

TIRS-240   The LDCM TIRS shall transition from a safe state in which operational environments are maintained to a fully operational condition within 1 minute of receipt of command.

Rationale: The intent is to be able to acquire fully compliant imagery in as short a time as possible within reason to not damage the instrument. This transition should be complete in a single ground contact.

5.3   Data Processing Algorithms

The following section describes the allowable set of data processing algorithms required to make corrections to the TIRS image and ancillary data; to detect, evaluate and correct systematic errors in the TIRS image and ancillary data; and to use government-provided support data to correct residual errors in the TIRS image and ancillary data so that the resulting corrected LDCM data meet the imagery requirements of Section 5.4 - 5.7. The limitation on data reprocessing is to prevent the use of an open-ended "fix it on the ground" approach that would allow, for example, image-based band registration correction methods. Such methods tend to be highly data dependent making it difficult to verify that performance requirements are met in general rather than only for selected test data sets.

5.3.1   Radiometric Correction Algorithms

Information: The radiometric correction algorithms correct the TIRS raw detector sample data, so that the radiometrically corrected TIRS image data meet the radiometric performance requirements in Section 5.4.

5.3.1.1 Detector Radiometric Response Determination

TIRS-247   The radiometric response determination algorithm shall calculate the coefficients required to calculate raw DN number as a function of incident spectral radiance for each detector.

Note: Pre and post image interval blackbody views, instrument temperatures and temperature sensitivity coefficients may be used as necessary for response coefficient determinations.

5.3.1.2 Conversion to Radiance

TIRS-250   The conversion to radiance algorithm shall take the raw output of each detector in digital numbers and convert it to spectral radiance (W/m^2-sr-μm) using the detector-by-detector radiometric response coefficients from 5.3.1.1.

5.3.1.2.1   Conversion to Radiance Algorithm Restrictions

TIRS-252   The conversion to radiance algorithm shall not rely on the content of the specific scene being corrected to determine the response coefficients.

5.3.1.3 Conversion to Temperature

TIRS-254   The conversion to temperature algorithm shall take the radiance from 5.3.1.2 and convert it to an equivalent blackbody temperature (in K).

5.3.1.4 Inoperable Detector Replacement

TIRS-256   The inoperable detector replacement algorithm shall replace the responses from detectors failing to meet the requirements for operability with values estimated from the surrounding detectors.

5.3.1.4.1   Inoperable Detector Replacement Methods

TIRS-258   The inoperable detector replacement algorithm shall provide selectable replacement methods including, but not limited to nearest-neighbor replacement and linear interpolation replacement.

5.3.2   Geometric Correction Algorithms

Information: The algorithms which correct for georegistration, geolocation and other geometric effects register radiometrically corrected TIRS image data to an absolute Earth coordinate reference system so that the resulting geometrically corrected LDCM data meet the geometric and geolocation performance requirements in section 5.7.

5.3.2.1 Ancillary Data Preprocessing

TIRS-262   The ancillary data preprocessing algorithm shall operate on the TIRS ancillary data to detect and correct erroneous ancillary data, perform units rescaling and coordinate system conversions, and apply ancillary data calibration corrections (e.g., clock correction, response/transfer function compensation, temperature sensitivity compensation). Auxiliary calibration parameters, quality thresholds, and other reference data sets may be used in this process.

Information: The resulting corrected TIRS ancillary data are used by subsequent geometric correction algorithms.

5.3.2.2 Line-of-Sight (LOS) Model Creation

TIRS-265   The LOS model creation algorithm shall use preprocessed ancillary data in conjunction with auxiliary calibration parameters to construct a model that relates each TIRS pixel line-of-sight to an absolute Earth-referenced coordinate system, such as Earth Centered Inertial of Epoch J2000.

5.3.2.2.1   *LOS Model Creation Algorithm Restrictions*

TIRS-267   The LOS model creation algorithm shall not use image-derived measurements to improve accuracy.

5.3.2.3 Line-of-Sight Projection

TIRS-269   The LOS projection algorithm shall use the TIRS LOS model in conjunction with the WGS84 G1150 or current version, Earth model to intersect each pixel line-of-sight with the Earth's surface, as defined in the following sections.

5.3.2.3.1   *LOS Projection to the Earth Ellipsoid Surface*

TIRS-271   The LOS intersection algorithm shall intersect each pixel line-of-sight with the WGS84 Earth ellipsoid surface.

5.3.2.3.2   *LOS Projection to the Terrain Surface*

TIRS-273   The LOS intersection algorithm shall intersect each pixel line-of-sight with the Earth's topographic surface as defined by government-furnished digital elevation data accurate to 12 meters (90% linear error).

5.3.2.3.3   *LOS Projection Algorithm Restrictions*

TIRS-275   The LOS intersection algorithm shall not use image-derived measurements to improve accuracy.

5.3.3   Image Resampling

TIRS-277   The image resampling algorithm shall interpolate at-sensor radiance values for Earth-referenced sample points from the radiometrically corrected TIRS image data.

5.3.3.1 Input Image to Resampled Output Image Mapping

TIRS-279   The image resampling algorithm shall use the line-of-sight projection algorithms of 5.3.2.3 to geometrically remap the input radiometrically corrected pixels from 5.3.1 to an output Earth-referenced map projection coordinate system.

5.3.3.2 Resampling Interpolation Method

TIRS-281   The image resampling algorithm shall use the cubic convolution algorithm [Reference 1] for image interpolation.

5.3.4   Data Processing Algorithm Performance

TIRS-283   The radiometric correction algorithms of section 5.3.1, the geometric correction algorithms of section 5.3.2, and the image resampling algorithms of section 5.3.3 shall create a radiometrically and geometrically corrected TIRS image

(both spectral bands) for a WRS-2 scene-sized area, at a ground sample distance
of 30 m for each spectral band, using one commercially available off-the-shelf
workstation, in 0.5 hours or less.

Rationale: The TIRS data shall be oversampled from the native sensor resolution to a ground
sample distance of 30 m to facilitate registration with 30 m-resolution OLI data.

5.4   Spectral Bands

5.4.1   Spectral Bandpasses

5.4.1.1 Spectral Band Edges

TIRS-287   The band edges for each spectral band shall fall within the range of the
minimum lower band edge and the maximum upper band edge as listed in Table
5-1.

Note: The Full-Width-Half-Maximum (FWHM) points of the relative spectral radiance
response curve define the bands edges for each spectral band. The shortest wavelength with
0.5 of peak relative response is the lower band edge; the longest wavelength with 0.5 of peak
relative response is the upper band edge.

5.4.1.2 Center Wavelength

TIRS-291   The center wavelength of the spectral response, the mid-point between the
band's upper and lower band edges, shall be the values listed in Table 5-1
within the specified tolerances also listed in Table 5-1.

Table 5 - 1   Table Thermal Spectral Bands and Bandwidths

#	Band	Center Wavelength (nm)	Center Wavelength Tolerance (±nm)	Minimum Lower Band Edge (nm)	Maximum Upper Band Edge (nm)
10	Thermal 1	10800	200	10300	11300
11	Thermal 2	12000	200	11500	12500

5.4.2   Spectral Band Shape

5.4.2.1 Spectral Flatness

5.4.2.1.1 Flatness Between Band Edges

The system relative spectral radiance response between the lower band edge (lowest wavelength with 0.5 response) and the upper band edge (highest wavelength with 0.5 response) is required to have the following properties:

5.4.2.1.1.1 Average Response

TIRS-320   The average relative spectral radiance response shall be greater than 0.8.

5.4.2.1.1.2 Minimum Response

TIRS-322   No relative spectral radiance response shall be below 0.4.

5.4.2.1.2 *Flatness Between 0.8 response points*

TIRS-324   The system relative spectral radiance response between the minimum wavelength within the band with a 0.8 response and the maximum wavelength within the band with a 0.8 response point shall always exceed 0.7.

5.4.2.2 Out of Band Response

TIRS-326   The ratio of the integrated relative spectral radiance response outside the 0.01 response points of each defined spectral band and between 3000 and 20000 nm to the integrated relative spectral radiance response between the 0.01 response points of each defined band shall be less than 2%.

TIRS-327   The ratio of the integrated relative spectral radiance response outside the 0.01 response points of each defined spectral band and below 3000 nm to the integrated relative spectral radiance response between the 0.01 response points of each defined spectral band shall be less than 0.5%.

TIRS-328   The integrated responses will be weighted by the radiance from a 300K blackbody summed with the radiance from a Lambertian surface of 100% reflectance illuminated by the sun at a zenith angle of 30°. The MODTRAN 4 [Reference 2, Section 2.4] "Chkur" solar spectrum shall be used for this calculation. The 0.01 response points are the points closest to the center wavelength where the response first drops to 0.01 of the peak response on each side of the center wavelength. Electrical crosstalk is not included within this requirement.

5.4.2.3 Relative Spectral Response - Edge Slope

5.4.2.3.1 *Wavelength Intervals - Case 1*

TIRS-331   The wavelength interval between the first 0.05 and the first 0.50 relative response points and the last 0.50 and the last 0.05 relative response points shall not exceed the values in Table 5-2.

5.4.2.3.2 *Wavelength Intervals - Case 2*

TIRS-333   The wavelength interval between the 0.01 relative response points and the
corresponding 0.50 response band edge shall not exceed the values in Table 5-2.

Table 5 - 2   Spectral Edge Slope Intervals for Thermal Bands

Band #	Lower Edge Slope Interval 0.01 to 0.50* (nm)	Lower Edge Slope Interval 0.05 to 0.50* (nm)	Upper Edge Slope Interval 0.50 to 0.05* (nm)	Upper Edge Slope Interval 0.50 to 0.01* (nm)
10	400	300	300	400
11	400	300	300	400

*Normalized to peak spectral response for the band

5.4.3 Spectral Uniformity

TIRS-356   Within a band the measured FWHM bandwidths for each detector shall be
within ±5% of the measured mean FWHM bandwidth. Within a band the
measured center wavelengths for each detector shall be within ± 50 nm of the
measured mean center wavelengths. Additionally, see Section 5.5.2.3.

5.4.4 Spectral Stability

TIRS-358   Band center wavelengths and band edges shall not change by more ± 50 nm
over the life of the mission.

5.4.5 Spectral Band Simultaneity

TIRS-360   For any point within a single scene observed by the TIRS, the TIRS shall
acquire data for all spectral bands within a 2.5-second period.

Rationale: Controlling the thermal band simultaneity limits the time over which the
decorrelation of spacecraft pointing knowledge errors degrades thermal band-to-band registration
accuracy. The LDCM Observatory IRD controls the relative attitude knowledge over 2.5 seconds
(IRD-329). This spectral band simultaneity requirement makes the band sampling interval
correspond to the IRD spacecraft attitude knowledge requirement time interval.

5.5 *Spatial Performance*

5.5.1 Ground Sample Distance

TIRS-364   Image sensor data shall provide a pixel-to-pixel increment, in the in-track and
cross track directions, equivalent to a GSD 120 m or less for both thermal bands
across the WRS-2 scene.

5.5.2 Spatial Edge Response Slope

TIRS-366 The spatial relative edge response slope for the thermal bands after radiometric correction per 5.3.1.2, shall conform to the criteria described in the following subsections. These edge response criteria apply to the near field response within 10 pixels of the edge.

Note: The relative edge response, in the context of this section and all of its subsections, is the normalized response of the imaging system to an edge. That is, the relative edge response is normalized so that the mean low-side steady state edge response is set to zero and the mean high-side steady state edge response is set to 100%.

Figure 5 - 1   Relative Edge Response

5.5.2.1 Relative Edge Response Slope

TIRS-371 The spatial relative edge response slope for the thermal bands after radiometric correction per 5.3.1.2 (slope between 40% and 60% response points, see Figure 5-1 shall exceed 0.007 / meter in both the in-track direction and the cross-track direction across the entire field-of-view.

Note: The relative edge response slope is defined as the slope between the 40% and 60% response points as depicted in Figure 5-1.

5.5.2.2 Edge Extent

TIRS-374 The edge extents for the thermal bands shall be less than 150.0 m in both the in-track direction and the cross-track direction for radiometrically corrected image sensor data, per paragraph 5.3.1.2, across the entire field-of-view.

Rationale: Imaging system simulations have shown that certain types of image degradations (e.g., ghost images with small displacements) can significantly degrade the overall edge response performance even when their effect on the central 40%-60% portion of the edge is minimal. Including a specification that covers more of the edge better protects against this type of localized degradation.

Note: The edge extent is defined as the horizontal distance, in meters, between the 10% and 90% relative response points as depicted in Figure 5-1.

5.5.2.3 Spatial Edge Response Uniformity

TIRS-378   The relative spatial edge response slope shall not vary by more than 10% (maximum deviation from the band average, 100%*(max - avg) / avg) in each band across the field-of-view.

TIRS-379   The relative spatial edge response slope shall vary by not more than 20% (maximum deviation from the two-band average) between spectral bands 10 and 11.

Rationale: This specification ensures consistent spatial performance across the field of view and across the spectral bands to reduce application performance sensitivity to target location within the FOV and control spectral mixing due to spatial effects.

5.5.2.4 Spatial Edge Response Overshoot

TIRS-382   The overshoot of any spatial edge response for all bands shall not exceed 5%.

Note: Overshoot applies to both the high (100% response) and low (0% response) sides of the edge, as shown in Figure 5-1, so that the maximum response is less than 105% and the minimum response is greater than -5%.

Comment: The overshoot requirement is intended to limit ringing at the edge.

5.5.2.5 Spatial Edge Response Ripple

TIRS-386   Edge response ripple for all bands shall not exceed 5% for TIRS image data.

Note: Ripple applies to both the high (100% response) and low (0% response) sides of the edge so that the response is greater than 95% beyond the 95% response point and the response is below 5% beyond the 5% response point.

5.5.3 Spatial Aliasing

TIRS-389   The product of the relative edge response slope and the GSD provided by TIRS image data shall be less than 1.0 for both the in-track and cross-track directions.

Rationale: This specification protects against data undersampling by ensuring that the sample spacing (GSD) is commensurate with the actual edge slope performance.

5.5.4 <u>Stray Light Rejection and Internal Scattering</u>

Definition: A light rejection scene or a scene to assess internal light scattering is defined as follows:

- The TIRS image data are collected from a circular region having a radius = 0.25 degrees and having a uniform target radiance = LT.

- That target region is surrounded by an annular region having an inner radius = 0.25 degrees and an outer radius = 25 degrees and having a uniform background radiance = LB.

- When LB = LT, the TIRS image data radiance measured at the center of the target region has a nominal value = LT.

All angles are measured relative to the TIRS nadir view.

TIRS-397   The magnitude of the change in the TIRS image measured radiance for all spectral bands at the center of the light rejection scene shall be less than 0.004 times the magnitude of the difference between LB and LT, where the target radiance is $L_{typcial}$ and background radiance levels range from a minimum of L_{240K} to a maximum of L_{330K}.

5.5.5 <u>Ghosting</u>

For two dimensional objects subtending an angle up to 1.5 deg with:

- a radiance level between 95% and 100% of L_{Max} and

- located at a position anywhere in the TIRS telescope full FOV,

TIRS-403   the signal from the object at N pixels away from the object edge shall be less than the values in Table 5-3.

Table 5 - 3   Ghosting Requirements

Distance From Edge (N pixels)	Maximum Signal
Between the 5% Relative Edge Response point and 10 pixels	Less than the linear threshold from 5% of L_{Max} to 6.5% of $L_{Typical}$ at 10 pixels.
Between 10 and 30 pixels	Less than the linear threshold from 6.5% of $L_{Typical}$ at 10 pixels to 2% of $L_{Typical}$ at 30 pixels
Greater than 30 pixels	Less than 2% of $L_{Typical}$

Notes:

(1) L_{Max} and $L_{Typical}$ are defined in Table 5-6.

(2) The entire range of N pixels may not be testable for all telescope FOV positions. For example, as the test object moves further off the instantaneous FOV of the active FPA, the closest pixel that can be tested moves further from the edge of the object.

(3) The contribution of diffuse stray light to the signal is not included.

5.5.6 Bright Target Recovery

TIRS-423   The thermal band data shall be such that for an image pixel that has been exposed to a pixel-sized area at a radiance level of less than or equal to that corresponding to a blackbody temperature of 500K, the pixels outside the 11 x 11 region around that pixel are not altered by more than 1% of their radiance at or above $T_{Typical}$.

Rationale: The "pixel-sized area at 500K'' translates to an active fire at a temperature of 1000K in about 20% of the pixel (with the rest of the pixel near 300K). This should allow imaging in regions in the vicinity of typical controlled agricultural fires, though areas in the vicinity of large forest fires could be contaminated.

5.6   Radiometry

5.6.1 Absolute Radiometric Uncertainty

TIRS-427   The thermal band absolute radiometric uncertainty shall be as given in Table 5-4 with all uncertainties established relative to National Institute for Standards and Technology (NIST) standards. This requirement applies to extended, spatially uniform, unpolarized targets. Uncertainty estimates include the NIST standard uncertainties.

Table 5 - 4   Thermal Bands Absolute Radiometric Uncertainty Requirements

Equivalent Blackbody Temperature Range	Absolute Radiance Uncertainty (1-sigma)
260 K - 330 K	<2%
240K - 260K; 330K - 360K	<4%

5.6.2 Radiometric Precision

5.6.2.1 Pixel Noise Equivalent Delta Temperatures

TIRS-441   For uniform scene temperatures between 240 K and 360 K extending over the full FOV of TIRS, and for a data collection period corresponding to a WRS-2 scene (~ 25 seconds at the nominal frame rate), the median detector standard deviation when converted into radiance units shall be ≤ 0.059 W/m^2 sr μm for the 10.8 μm channel and ≤ 0.049 W/m^2 sr μm for the 12.0 μm channel. This includes quantization noise.

Any detector with a standard deviation more than 1.25 times these values shall be considered out-of-specification. The Noise Equivalent Delta Temperature (NEΔT) for each channel for several temperatures is given in Table 5-5.

Table 5 - 5   Noise Equivalent Delta Temperatures (NEΔT)

Channel	NEΔT				
	240 K	260 K	300 K	320 K	360 K
10.8 μm	0.80 K	0.61 K	0.40 K	0.35 K	0.27 K
12.0 μm	0.71 K	0.57 K	0.40 K	0.35 K	0.29 K

5.6.2.2 Quantization Noise Limit

5.6.2.3 Pixel-to-Pixel Uniformity

The following environmental conditions and measurement approach apply to requirements 5.6.2.3.1, 5.6.2.3.2, and 5.6.2.3.3.

- The thermal band banding requirements apply to uniform sources with the radiance corresponding to a blackbody temperature above 260K and below 330 K.

- The thermal band radiometric values are corrected per paragraph 5.3.1.2.

- The thermal band temporal noise is averaged to verify compliance with this specification.

Note: A pixel column is a consecutive sequence of pixels generated by a single detector.

5.6.2.3.1 Full Field of View

TIRS-503   The standard deviation of all pixel column average radiances across the FOV within a band shall not exceed 0.5% of the average radiance.

This requirement is met when:

$$\sqrt{\frac{\sum_{i=1}^{N}(\bar{L}_i - \bar{L}')^2}{N-1}} \le 0.005 \cdot \bar{L}'$$

Where:

$\bar{L}_i$ is the temporal average response of column i;

$\bar{L}'$ is the 2 dimensional (column and line) average response for a spectral band;

N Total number of pixels in a spectral band line.

5.6.2.3.2 Banding

TIRS-507   a) The root mean square of the deviation from the average radiance across the full FOV for any 100 contiguous pixel column averages of radiometrically

corrected TIRS image data within a band shall not exceed 0.5% of that average radiance.

This banding requirement is met when for all n:

$$\sqrt{\sum_{i=n}^{n+99} (\bar{L}_i - \bar{L}')^2 / 100} \leq 0.005 \cdot \bar{L}'$$

Where:

n is the pixel number in a line of data;

$\bar{L}_i$ is the average radiance of pixel column i;

$\bar{L}'$ is the 2 dimensional (column and line) average response for a spectral band.

TIRS-514   b) The standard deviation of the radiometrically corrected values across any 100 contiguous pixels column averages of TIRS image data within a band shall not exceed 0.5% of the average radiance across the full FOV.

Note: The average radiance across the FOV is used here merely as a reference for deriving the magnitude of the 0.5%. The mean in the standard deviation calculation is, by definition, the mean of the 100 pixel columns and not the entire FOV mean

This banding requirement is met when for all n:

$$\sqrt{\sum_{i=n}^{n+99} (\bar{L}_i - \bar{L})^2 / 99} \leq 0.005 \cdot \bar{L}'$$

Where:

n is the pixel number in a line of data;

$\bar{L}_i$ is the average radiance of pixel column i ;

$\bar{L}$ is the average radiance across the 100 pixel columns

$$\bar{L} = \sum_{i=n}^{n+99} L_i / 100$$

$\bar{L}'$ is the 2 dimensional (column and line) average response for a spectral band.

5.6.2.3.3 Streaking

TIRS-525   The maximum value of the streaking parameter within a line of radiometrically corrected, TIRS data shall not exceed 0.005.

The streaking parameter is defined by the following equation:

$$S_i = \left| \bar{L}_i - \frac{1}{2} \left(\bar{L}_{i-1} + \bar{L}_{i+1} \right) \right| / \bar{L}_i$$

Where:

$\overline{L}_i$ is the average radiance of pixel column i;

$\overline{L}_{i-1}$ and $\overline{L}_{i+1}$ are similarly defined for the (i-1)th and (i+1)th pixel columns.

5.6.2.4 Coherent Noise

TIRS-532   Each pixel column in a uniform scene or WRS-2 sized dark background image in any band acquired by the TIRS, after radiometric calibration per 5.3.1.2, shall only contain coherent noise (CN) components with relative amplitude[1] , A_{rel} (in %), that are lower than the maximum amplitude level, A_{relmax} denoted by the following formula (see Figure 5-2):

$A_{relmax}(f) = 2.4$: For f <0.1

$A_{relmax}(f) = 9.0 \, f + 1.5$: For f ≥0.1

Where:

f is frequency in cycles/pixel.

The A_{rel} is the ratio of an individual CN component zero-to-peak amplitude to the product of 3 times the standard deviation of a full WRS-2 scene and the ratio of the required median NEΔL @ $L_{typical}$ to the actual observed median NEΔL @ $L_{typical}$ (Section 5.6.2.1) i.e. ,

A_{rel} = (Amplitude of Coherent component) / (3 times the standard deviation of the image* NEΔL$_{Req}$/NEΔL$_{Obs}$)*100.

The CN components amplitudes are derived from the average PSD of multiple observations[2] and after frequency domain subtraction of any 1/f noise and the mean white noise floor level. Detectors corresponding to pixel columns are only considered to have failed this requirement, that is, are out-of-specification and subject to the limitations of section 5.6.5.3, if the probability of exceeding A_{relmax} is greater than 80%.

Notes:

1. The individual CN component amplitude is the amplitude of the wave pattern generated, for example, in the model of a sine wave it will be the amplitude of a sine wave defined as $A\sin(\omega t + \phi)$.

2. Multiple collects are used to reduce uncertainty in analysis and establish a frequency dependent threshold (related to standard deviation) to filter out noise spectra peaks that are due to random fluctuations about the noise floor as opposed to coherent noise.
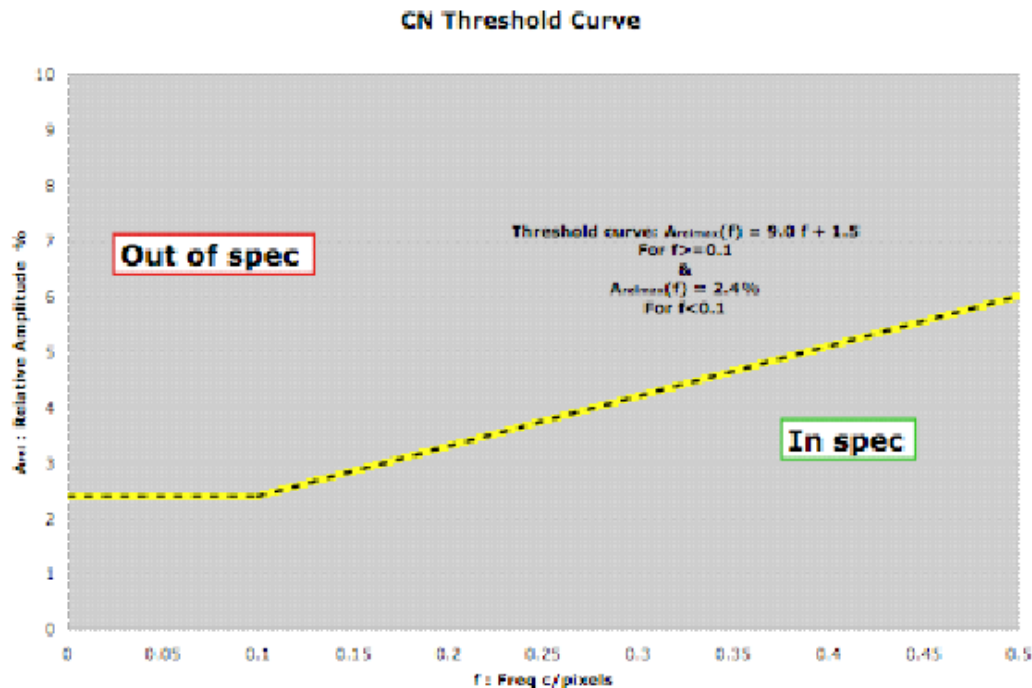
CN Threshold Curve

Figure 5 - 2   Coherent Noise Threshold Curve

5.6.3   Saturation Temperatures

TIRS-545   The thermal band shall detect, without saturating, signals from the noise floor (NEΔL =0.059 W/(m^2 sr μm) for the 10.8 μm channel and NEΔL = 0.049 W/(m^2 sr μm) for the 12.0 μm channel) up to the maximum radiance (L_{max}) as shown in Table 5-6.

Table 5 - 6   Reference Temperatures

Band#	Typical Temperature	Typical Radiance (W/m^2 sr μm)	Saturation Temperature (K)	Saturation Radiance (W/m^2 sr μm)
	$T_{Typical}$	$L_{Typical}$	T_{Max}	L_{Max}
10	300K	9.64	360K	20.5
11	300K	8.94	360K	17.8

5.6.4   Radiometric Stability

TIRS-547   Thermal band data for all pixels, after radiometric calibration per 5.3.1.2, for radiometrically constant targets with radiances greater than or equal to the radiance corresponding to $T_{Typical}$, shall not vary by more than plus or minus

0.7% (1-sigma) of their radiance over a 40 minute period. Pixels failing this specification are considered out-of-specification and are subject to the limitations of paragraph 5.6.5.3.

5.6.5 Dead, Inoperable and Out-of-Specification Detectors

5.6.5.1 Dead or Inoperable Detectors

TIRS-550   Less than 0.1% of detectors in either spectral band shall be dead or inoperable.

Note: Dead or inoperable detectors may be removed from any performance averages and standard deviations for determining compliance to performance specifications.

5.6.5.2 Adjacent Dead or Inoperable Detectors

TIRS-553   There shall be no across track adjacent dead or inoperable detectors.

5.6.5.3 Out-of-Spec Detectors

TIRS-555   Less than 0.25% of the operable detectors in any spectral band in any WRS-2 scene shall fail to meet one or more performance requirements.

Note: Out-of-spec detectors may be removed from any performance averages and standard deviations for determining compliance to performance specifications.

5.7 Navigation and Registration

5.7.1 Line-of-Sight Stability

TIRS-559   The LDCM TIRS internal mechanical alignment shall be stable such that each thermal detector line of sight varies relative to its modeled location by less than 27 micro-radians, 3-sigma for each axis relative to the TIRS mounting interface, over the full thermal operational design temperature range over each 16-day observation cycle.

Rationale: Stability induced alignment errors cannot be backed out of the on-orbit calibration data. Detector line-of-sight stability is needed to ensure accurate band-to-band registration and absolute geolocation. The stability of the TIRS focal plane's alignment relative to the TIRS optical system and the stability of the TIRS optical system's alignment relative to the TIRS mounting interface are two components of this overall alignment stability.

Note: This requirement covers all sources of random LOS instability including thermal, optical, and jitter effects. Systematic optical and/or thermal effects that are modeled and corrected by using the line of sight algorithm of section 5.3.2.2 are not included in this requirement.

5.7.2 Timing Accuracy

TIRS-563   The LDCM TIRS shall time tag TIRS instrument data with an accuracy relative
                  to the LDCM Observatory time reference of 1 millisecond or less, 3-sigma.

Rationale: To ensure that the image data can be synchronized with the ancillary data the two
time references should be accurate to each other within 1 millisecond. The LDCM TIRS will
receive a one pulse per second from the LDCM spacecraft for time synchronization.

TIRS-565   The sample timing characteristics for each detector column shall be known to an
                  accuracy of 1.5 milliseconds, 3-sigma, including any latency or detector
                  response time effects.

Rationale: Detectors with response times that are a significant fraction of the pixel sampling
time, such as microbolometers, introduce an along-track phase shift in the effective sample
location. This must be characterized to properly locate the image pixels. This requirement
applies to detector columns to account for the effects of TDI.

5.7.3 Registration and Geolocation Accuracy

The following sections detail the thermal band image geometric accuracy requirements that
must be achieved when the correction algorithms provided in accordance with Sections 5.3.1
and 5.3.2 of this specification are applied to LDCM mission data. The specific correction
algorithms that apply to each geometric imagery requirement are shown in Table 5-7.

Table 5 - 7 Image Requirement to Processing Algorithm Verification Mapping

	5.3.1 Radiometric Correction	5.3.2.1 Ancillary Data Processing	5.3.2.2 Line-of-Sight (LOS) Model Creation	5.3.2.3.1 LOS Projection to WGS84 Ellipsoid Surface	5.3.2.3.2 LOS Projection to Terrain Surface	5.3.3 Image Resampling
5.7.3.1 Thermal Band Registration Accuracy	X	X	X	-	X	X
5.7.3.2 Thermal Band Geodetic Accuracy	X	X	X	X	-	X

5.7.3.1 Registration Accuracy

TIRS-596   Corresponding pixels from the two thermal bands in TIRS data that have been geometrically corrected, including compensation for the effects of terrain relief shall be co-registered with an uncertainty of 18 meters or less in the line and sample directions at the 90% confidence level.

Rationale: This level of band registration accuracy represents the same pixel fraction (0.15) as is required for OLI internal band registration. Band registration is critical for many applications.

5.7.3.2 Geodetic Accuracy

TIRS-599   The pixels for targets at the Earth's topographic surface in geometrically corrected TIRS thermal band data shall be located relative to the WGS84 geodetic reference system, G1150 or current version, with an uncertainty less than or equal to 76 meters (90% circular error*), excluding terrain effects. This specification applies to the horizontal error of ground control points measured in the processed image, after compensation for control point height.

Rationale: Including an end-to-end geolocation accuracy requirement provides a parent requirement from which more detailed alignment knowledge and stability and processing algorithm performance requirements can be derived. This level of accuracy is based on the corresponding OLI requirement (65 meters CE90) with additional allocations for OLI to TIRS and TIRS internal alignment knowledge and stability.

5.8   In-Flight Calibration Sources

TIRS-602   TIRS shall incorporate a minimum of one full field, full aperture, and full system NIST-traceable calibration source.

TIRS-603   If two on-board calibration sources are not used, TIRS shall include a full aperture deep space view as the second calibration source.

TIRS-605   TIRS shall incorporate a device by which the linearity of the TIRS with respect to radiance can be characterized within a period of 2 orbits without affecting normal imaging operations.

TIRS-606   The calibration source shall operate at a minimum of two temperatures.

5.8.1   Calibration Source Availability

TIRS-608   The calibration sources shall be available for use at any point in the orbit.

TIRS-609   The calibration sources shall be available for use for 30 seconds every 5 minutes over a 50 minute period.

Rationale: Enables routine periodic measurement of 1/f noise and short-term stability of TIRS.

5.8.2 Calibration Sequence Timing

TIRS-612   The LDCM TIRS shall complete a calibration sequence using both calibration
                  sources in 5 minutes or less.

Rationale: Limits the time TIRS can spend performing calibration.

6 Structural and Mechanical Systems

TIRS-614   The LDCM TIRS structure shall be of sufficient strength and stiffness to maintain structural integrity and withstand all ground testing, handling, transportation, launch, launch vehicle separation, and mission orbit environments.

TIRS-615   The LDCM TIRS shall provide when configured for launch a fixed-base fundamental resonant mode frequency of greater than 60 Hz.

Rationale: This requirement allocates a portion of that stiffness constraint to TIRS.

TIRS-617   The LDCM TIRS shall have a fundamental resonant mode frequency in its on-orbit configuration of 5.8 Hz +/-1 Hz.

Rationale: Sufficient separation between the instrument resonant mode and the spacecraft attitude control system is required to avoid control errors.

TIRS-619   The LDCM TIRS structure shall provide a mounting interface for the TIRS to the LDCM Spacecraft.

TIRS-620   The LDCM TIRS structural and mechanical interface shall accommodate manufacturing tolerance, structural, and thermal distortions.

TIRS-621   The LDCM TIRS structural system shall provide an external optical alignment device.

Rationale: The TIRS instrument needs to be co-aligned with the spacecraft inertial reference system and with the Operational Land Imager.

TIRS-623   The LDCM TIRS optical alignment device's orientation relative to the TIRS optical axis shall be known to an accuracy of 600 micro-radians, 3-sigma for each axis.

Rationale: The alignment device (cube) will be used to determine the prelaunch alignment between the TIRS optical axes and the spacecraft attitude determination reference system. Thus, knowledge of the alignment between the cube and the TIRS optical system is necessary to determine the relationship between the TIRS boresight and the spacecraft coordinate system during prelaunch alignment measurements. Since the TIRS to attitude determination system alignment is likely to change somewhat at launch due to launch shift and zero-G release, this alignment will also be ascertained on-orbit. The accuracy of the prelaunch measurement is thus not critical for geolocation accuracy but is needed to ensure proper alignment of the instrument(s) and attitude sensors and to initialize the on-orbit calibration procedure.

TIRS-625   The LDCM TIRS mechanical system shall provide a gaseous purge fitting.

Rationale: To allow a positive dry nitrogen or dry air gas purge within the TIRS during all stages of instrument and satellite integration, test, shipment, launch site processing, and while on the launch pad up to T-0.

7   Thermal Control

TIRS-628   The LDCM TIRS shall be thermally safe for continuous operations in all modes.

Rationale: The TIRS design and operation needs to be thermally safe when in Survival Mode assuming power is provided by the spacecraft and in all other modes with power distributed by TIRS.

TIRS-630   The LDCM TIRS shall maintain its subsystems within their survival temperature range when the TIRS is in Survival Mode when the spacecraft supplies power to survival heaters.

Rationale: During Observatory Safe Hold the observatory subsystems including instruments are allowed to thermally drift in order to minimize power consumption.

TIRS-632   The LDCM TIRS shall maintain subsystems within their design operational temperature range for nominal operations.

Rationale: During de-contamination of the FPA or other elements it is conceivable that components could exceed their design operational temperatures but not their survival temperatures.

TIRS-634   The LDCM TIRS precision temperature control shall be located within the TIRS, provided by TIRS, controlled by the instrument electronics and use power from the overall TIRS power budget.

TIRS-635   The LDCM TIRS operational thermal range shall be reprogrammable on orbit.

TIRS-636   The LDCM TIRS survival heaters shall be on a power circuit independent of the TIRS instrument.

Rationale: TIRS survival heaters must be powered when the rest of the TIRS is powered off. Survival heaters are assumed on while TIRS is in the Survival or Off Mode.

8   Electrical System

TIRS-639   The LDCM TIRS shall provide protection from over voltage and under voltage conditions for power coming into the instrument.

TIRS-640   The LDCM TIRS shall not be damaged by the application of bus voltages between 0 and 35 volts direct current.

Rationale: Low voltage startup should not damage the instrument, it may not start up but it will not break.

TIRS-642   The LDCM TIRS shall physically isolate all power lines from signal lines.

Rationale: To protect communication circuits from high voltage TIRS should use shielded and separate cables.

9   Flight Software

Note: This section is only applicable if TIRS has software.

9.1   General

TIRS-647   The LDCM TIRS flight software shall be reprogrammable on orbit, excluding firmware (FPGAs and ASICs).

Rationale: This requirement is not intended to have embedded flight software in FPGA or permanently code state machines changed on-orbit.

TIRS-649   The LDCM TIRS shall receive flight software loads across multiple contacts.

TIRS-650   The LDCM TIRS shall receive flight software updates by patches at the function, unit or module level.

TIRS-652   The LDCM TIRS shall monitor flight software tasks or functions to detect for infinite loops or "hung" processes.

TIRS-841   The LDCM TIRS flight software shall verify the validity of all memory areas.

Rationale: To ensure that valid data/ instructions, etc. are in use. This task should run with a high enough frequency to fix environment induced bit flips.

TIRS-659   The LDCM TIRS flight software shall monitor and report the resource utilization by software subsystems or critical functions.

Rationale: To ensure that margins are maintain over the development life of the software.

TIRS-661   The LDCM TIRS flight software shall make resource utilization monitors available for downlink in telemetry.

Rationale: To verify functions are running smoothly and with expected CPU utilization.

TIRS-663   The LDCM TIRS flight software tasks shall have a defined execution priority.

Rationale: Because critical tasks need to execute before non-critical tasks.

TIRS-665   The LDCM TIRS flight software shall store the version identifier of reprogrammable software onboard.

TIRS-666   The LDCM TIRS firmware shall store the version identifier of the embedded software onboard.

TIRS-668   The LDCM TIRS flight software shall update any and all memory table locations through ground command table names.

TIRS-669   The LDCM TIRS flight software shall load any location of on-board memory by referencing its physical memory address.

TIRS-672   Upon command the LDCM TIRS flight software shall dump the entire memory of on-board processors.

Rationale: To support debugging efforts and provide telemetry state of the on-board flight software

9.2 Initialization

TIRS-683   The LDCM TIRS shall preserve contents of a processor event log after a cold restart or a warm restart.

9.2.1 **Cold Restart**

TIRS-685   The LDCM TIRS shall execute a cold restart of a processor's software from Read Only Memory in response to a ground command.

Rationale: This is a reboot of the flight software instruction set loaded from the non-volatile on-board memory (EEPROM, PROM, etc.) and does not require a power-on reset.

TIRS-687   The LDCM TIRS flight software shall execute a Cold Restart initialization process when starting execution from a hardware reset.

TIRS-688   The LDCM TIRS flight software shall execute a restart of a processor's software from Read Only Memory following a power cycle or hardware reset.

Rationale: This is a complete reboot of the flight software loaded from the non-volatile on-board memory (EEPROM, PROM, etc.).

TIRS-691   The LDCM TIRS flight software shall execute a Cold Restart when the number of failed Warm Restart attempts equals or exceeds a predetermined value.

TIRS-692   Upon receipt of a valid Cold Restart command, the TIRS flight software shall restart within 10 seconds.

Rationale: Placement of a 10 second limit for cold restart completion accomplishes the primary goal of a warm restart; i.e. a rapid boot-up and permits compliance with attainment of an instrument safe state within 45 seconds.

9.2.2 **Warm Restart**

9.3 Hardware Commands

TIRS-706   The LDCM TIRS onboard processors shall reset upon receipt of a hardware pulse via hardware pulse command.

Rationale: Flexibility is necessary to support debugging conditions that may not be known until after launch.

10 <u>Data Processing</u>

Note: This section is applicable whether or not TIRS has software.

10.1 General

TIRS-804   The LDCM TIRS shall possess sufficient non-volatile memory to contain two entire copies of the TIRS processor code image at launch.

TIRS-808   The LDCM TIRS shall protect against SEUs and other memory and processor errors.

Rationale: This can be done through the use of design features such as memory error detection and correction (EDAC), periodic refresh of critical hardware registers, processor and register majority voting, watchdog timers, etc.

TIRS-807   The LDCM TIRS shall detect and correct single bit memory errors.

Rationale: Because bit flips happen

TIRS-806   The LDCM TIRS shall detect and report multiple bit errors in memory.

Rationale: Because bit flips happen and not all errors can be corrected.

TIRS-805   The LDCM TIRS shall maintain a mapping of table name to memory address location.

TIRS-809   Upon command, the LDCM TIRS shall dump any location in program memory.

Rationale: To support debugging efforts and provide additional telemetry points which may have been unanticipated at development time.

TIRS-810   The LDCM TIRS memory dump capability shall not disturb nominal instrument task execution.

Rationale: This requirement is not to effect the on-going observatory operations or software processes. This requirement should only effect (replace or supplement or use excess wideband data) capability to get the memory dump telemetry on the ground.

TIRS-811   The LDCM TIRS shall implement independent time-based (watch-dog timer) monitoring circuits.

Rationale: On-board processors should use hardware "watch dog" timers, or some hardware implemented system independent of the CPU to interrupt stuck software.

10.2 Event Logging

TIRS-812   The LDCM TIRS shall time tag events logged in telemetry with an accuracy less than or equal to 250 milliseconds.

Rationale: A reported event would contain information on the source processor, flight software task or function, severity level, message identifier and informational string that identifies the cause. The event messages capture anomalous events, redundancy management switching of components and important system performance events and warm and cold restarts to the accuracy of command execution.

TIRS-813   The LDCM TIRS shall report all event messages in the observatory housekeeping telemetry.

10.3 Initialization

TIRS-814   The LDCM TIRS shall default to a known telemetry configuration following a Cold Restart.

10.4 Failure Detection, Protection, and Correction

TIRS-815   The LDCM TIRS shall automatically detect and report in telemetry hardware and software out of limit and fault conditions.

TIRS-816   The LDCM TIRS subsystems that perform self-diagnostics shall report the results in a diagnostic telemetry stream.

Rationale: Diagnostic data should be made available on the ground through special telemetry formats that are tailored for debugging and diagnostics.

TIRS-817   The LDCM TIRS subsystems that support self-diagnostics shall accept ground commands to run diagnostics and report the results in a diagnostic telemetry stream.

Rationale: Flexibility is necessary to support debugging conditions that may not be known until after launch.

TIRS-818   The LDCM TIRS shall reject invalid commands.

TIRS-819   The LDCM TIRS shall report rejected commands in housekeeping telemetry.

10.5 Hardware Commands

TIRS-820   The LDCM TIRS watchdog timer shall be enabled or disabled by a hardware pulse command.

Rationale: Flexibility is necessary to support debugging conditions that may not be known until after launch.

11 <u>Command & Data Handling</u>

11.1 General

TIRS-711   The LDCM TIRS shall be capable of maintaining the health and safe operations of all elements of the TIRS without ground support.

TIRS-712   The LDCM TIRS shall continuously monitor its health and safety.

TIRS-713   The LDCM TIRS shall report the health and safety of the TIRS components to the spacecraft.

TIRS-714   The LDCM TIRS reference time shall be accurate to within 50 microseconds or less, 3-sigma of each LDCM spacecraft 1-second timing pulse.

TIRS-715   TIRS shall lose no more than one scene of science data within each 4-day period.

Rationale: A single dropped bit of scene data defines the loss of a scene. The bit error rate is to limit the number of bits lost prior to transfer to the spacecraft interface.

11.2 Reserved

11.3 Telemetry

TIRS-719   The LDCM TIRS shall provide sufficient telemetry to ensure proper control and monitoring of TIRS health and safety, and to identify anomalous conditions.

Rationale: For proper insight into the state of health and on going instrument activities, memory dumps, housekeeping data, etc.

TIRS-721   The LDCM TIRS shall order telemetry by function within 1553 sub-addresses.

Rationale: Ordering the HK telemetry by function (such as power, temperature, instrument settings) allows the SC to read selected sub-address during contingency operations to monitor specific functions to provide the ground with state of health data.

TIRS-723   The LDCM TIRS shall provide the capability to select a telemetry stream definition from onboard storage via a single command.

TIRS-724   The LDCM TIRS shall generate and transmit real-time instrument housekeeping data to the LDCM spacecraft.

Rationale: Real-time HK data is needed to monitor and control the instrument.

TIRS-844   The LDCM TIRS shall complete loading of the 1553 telemetry housekeeping sub-address within 500 msec once per second.

Rationale: To protect against mixed time slice T/M packets (collisions during T/M read by the SC) this requirement allocates 1553 bus time to the task.

11.4 Command Capability

TIRS-727   The LDCM TIRS shall accept and execute discrete and hardware pulse
                  commands in real time only.

Rationale: TIRS will not have to have internal stored command capability

TIRS-729   The LDCM TIRS shall process real-time commands while concurrently
                  executing long-duration commands.

Rationale: Commands such as on-board processor uploads, imaging may take several minutes
and once these processes have started the instrument should be able to continue processing
normal functions.

TIRS-731   The LDCM TIRS shall validate, process, and execute commands

TIRS-732   The LDCM TIRS shall not execute a command that has failed validation.

TIRS-733   The LDCM TIRS shall report commands that fail validation in housekeeping
                  telemetry.

TIRS-734   The LDCM TIRS shall have no command lockout.

Rationale: There is no command to lock-out or permanently disable the TIRS instrument

TIRS-736   The LDCM TIRS shall access information from one or more separate data tables
                  stored in onboard RAM through a single command.

TIRS-737   The LDCM TIRS shall load a parameter of a table without loading the entire
                  table.

TIRS-738   The LDCM TIRS real-time command shall perform only one function, fully
                  identified in the command data field establishing a known state and condition.

Rationale: Using toggle commands can leave the state of a switch, box, etc. unknown. It is
better to have enables and disables be unique commands and not just toggle back and forth. A
toggle commands would not be permitted as they do not fully define the final state.

TIRS-740   The LDCM TIRS shall execute a command at a frequency of at least 4Hz.

TIRS-741   The LDCM TIRS shall begin command execution within 250.0 milliseconds
                  from the time the valid command is received by TIRS.

Rationale: To prevent undue delay in execution of commands that may lead to unpredictable
operation.

12 <u>Verification Cross Reference Matrix (VCRM)</u>

TBS.

APPENDIX